THE AGE AND SUCCESSION OF THE IGNEOUS ROCKS OF THE SIERRA NEVADA.[1]

THE following notes and suggestions on the age of the igneous rocks of the Sierra Nevada are the outgrowth of field work in two parts of the range; one portion being a strip thirty miles wide across the mountains just south of the fortieth parallel, chiefly in the area of the Chico, Bidwell Bar and Downieville sheets of the United States Geological Survey; the other portion that part of the range to the south of Cosumnes River, or approximately latitude 38° 30′ N. The succession has been made out only partially and for only certain districts, and the article should therefore be considered merely as a contribution to the subject which must be later revised, and can be fully treated of only after more field work and a more thorough study of the material now on hand.

Mr. Waldemar Lindgren has acquired a large amount of information concerning the district across the central part of the range from Sacramento to Lake Tahoe, the geological maps of which have been prepared under his direction, and much light may be expected when his results are published. The writer is indebted to Mr. Lindgren for friendly criticisms.

The Sierra Nevada as a topographic unit may be described, following Whitney,[2] as the mountain area lying to the east of the Great Valley of California and to the west of the Great Basin, extending from near the Tejon Pass at the south end of the Great Valley to Lassen Peak on the north. As thus defined, the

[1] Published by permission of the Director of the U. S. Geological survey.

The chemical analyses given in this paper, unless otherwise stated, have been made by Dr. W. F. Hillebrand of the U. S. Geological Survey, whose high standing as an analyst is well known.

[2] Auriferous Gravels of the Sierra Nevada, p. 7.

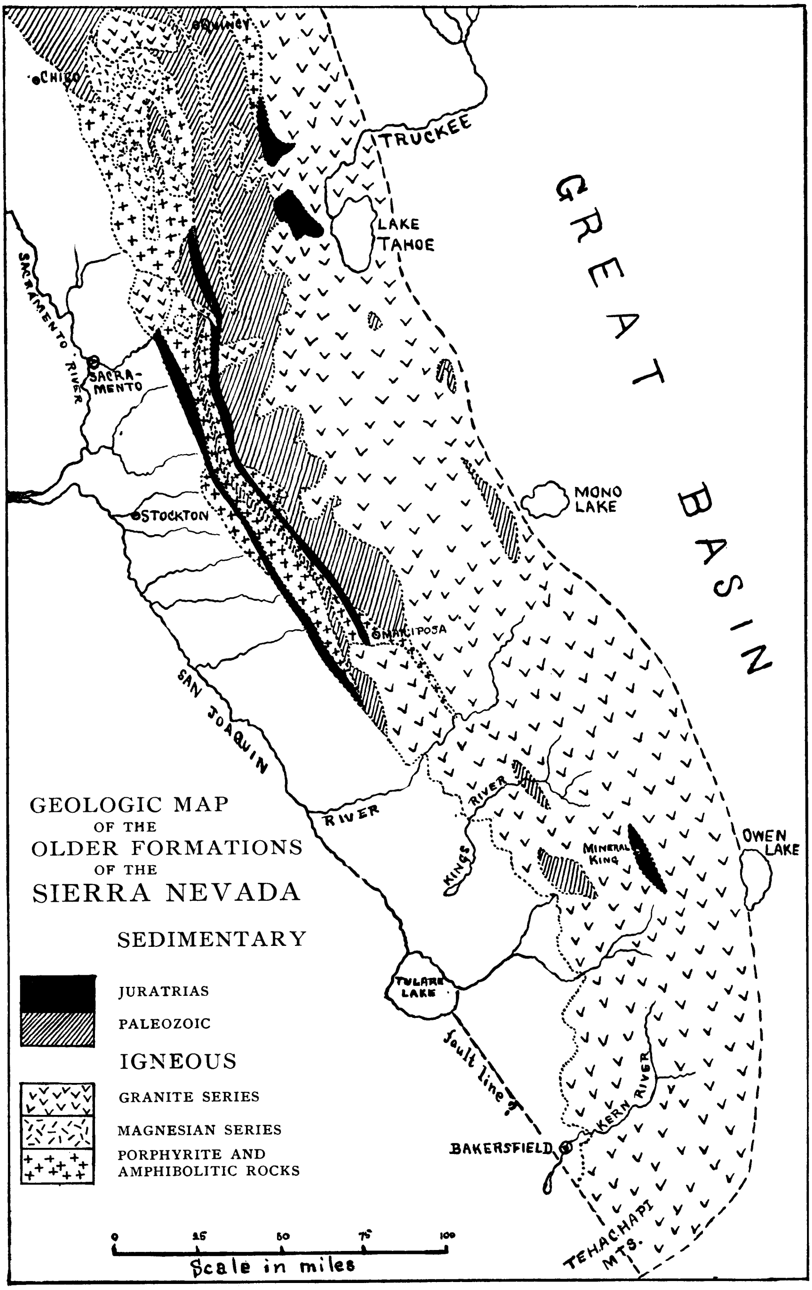
range lies wholly in the state of California, except the high granite spur lying just east of Lake Tahoe. Diller[1] has suggested, however, on geological grounds, that the range be limited on the north by the lavas of the Lassen Peak region, in the neighborhood of the North Fork of the Feather River, for to the north of this line there existed during Cretaceous time a great depression, which late in the Tertiary was filled in by the lava flows of Lassen Peak, which Diller considers as geologically related to the Cascade Range.

A little to the west of the Tejon Pass, according to Whitney,[2] "we pass at once from undisturbed Tertiary to strata of the same age, which are elevated at a high angle, and in so doing we leave the system of the Sierra and pass to that of the Coast Ranges." In a previous paper[3] the writer suggested that this line, separating little disturbed and highly disturbed beds, probably represents a line of faulting, the continuation of which further north is apparently followed by the San Joaquin and Sacramento Rivers. As is well known, the upper Cretaceous and Tertiary strata to the east of these rivers in the Sierra Nevada lie nearly horizontal, while to the west of it they are at nearly all points deformed. Adopting Diller's restriction of the range at its north end, the Sierra Nevada may be considered as terminating on the north, a little to the north of the North Fork of the Feather River; on the east at the west edge of the Great Basin; on the south at the Mojave Desert; and on the west at the hypothetical line of faulting above indicated. The eastern part of the Tehachapi Mountains will thus fall in the Sierra Nevada system. The geologic map (Plate VII) shows the range as thus restricted, the broken lines on the east and south being the line separating the Sierra Nevada from the Great Basin and the Mojave Desert. That portion of this line between Owen and Mono Lakes, and the portion east of Lake Tahoe coincide with a probable line of faulting, along which the Sierra has been elevated or the Great

[1] Eighth Annual Report, U. S. Geol. Surv., p. 404 and Plate XLV.

[2] Geol. Cal., Vol. I., p. 167.

[3] American Geologist, Vol. XIII., p. 248.



QUINCY
CHICO
TRUCKEE
LAKE TAHOE
GREAT BASIN
SACRAMENTO RIVER
SACRA-MENTO
STOCKTON
MONO LAKE
MARIPOSA
SAN JOAQUIN RIVER
KINGS RIVER
MINERAL KING
OWEN LAKE
TULARE LAKE
fault line ?
KERN RIVER
BAKERSFIELD
TEHACHAPI MTS.
GEOLOGIC MAP
OF THE
OLDER FORMATIONS
OF THE
SIERRA NEVADA
SEDIMENTARY
JURATRIAS
PALEOZOIC
IGNEOUS
GRANITE SERIES
MAGNESIAN SERIES
PORPHYRITE AND AMPHIBOLITIC ROCKS
0 25 50 75 100
Scale in miles

Basin depressed (or perhaps movements in both directions have occurred) in Tertiary time.

The Sierra Nevada, as thus outlined, appears to constitute a block of the earth's crust that has been practically rigid since middle Cretaceous time, although it has since, in common with most of California, experienced a considerable elevation, and there has been displacement by normal faults within the mass, particularly in Plumas county, at the north end of the range.

In another respect also the Sierra may be considered a geologic unit. The Tertiary lavas throughout the mass that have the widest distribution are very similar at distant points, and unlike Tertiary lavas in other adjacent areas, especially as to their form of occurrence and their relation in time. Thus the oldest flows of large extent were of rhyolite, succeeded by hornblende-pyroxene-andesite, chiefly in the form of tuff and breccia. This relation does not appear to hold good in the Lassen Peak region or in the Great Basin. The sediments of which the Sierra Nevada are in part composed are presumed to have been derived chiefly from an Archean land mass lying west of the central part of the state of Nevada, although it is by no means impossible that an Archean land area once existed on the site of the present Coast Range, and in that case part of the sediments may have been derived from the West. It is probable that there are within the Sierra Nevada formations ranging in age from Archean or Algonkian to Recent. Excepting, however, some Silurian fossils at the north end of the range, no evidence has thus far been found of rocks older than the Carboniferous, although in the northwest extension of the Auriferous Slate series of the Sierra Nevada in Siskiyou and Shasta counties, Diller and Fairbanks have collected Devonian fossils. On the geologic map (Plate VII.) only the older formations, constituting the Auriferous Slate series with the associated igneous rocks, are represented. On this map the Palæozoic corresponds with the Calaveras formation of the Gold Belt maps; the two narrow belts of Jura-Trias, on the west slope of the range, are the Mariposa beds; the Jura-Trias beds northwest of Lake Tahoe are the Sailor-Canyon and

Milton series, and the area in the southern part of the Sierra at Mineral King is probably Triassic in age. Under granite, which forms much the larger part of the range, are included the potash-poor granite or granodiorite of Becker, or tonalite of Vom Rath, and the porphyritic granite,[1] described in the Fourteenth Annual Report, United States Geological Survey. Nearly all the small areas noted on the map enclosed in schists or in basic igneous rocks are granodiorite, the porphyritic granite occurring chiefly along the crest of the range, especially in its southern part. The Magnesian series comprises serpentine, talc and tremolite schists with some other associated amphibolitic schists, the entire series being derived from basic igneous rocks. The porphyrites and amphibolitic rocks comprise the rocks laid down on the Gold Belt maps as diabase and porphyrite and amphibolite-schist derived therefrom, and altered igneous rocks which are now diorites, and which may be designated, following Cross, metadiorites, that is to say, diorites formed from other rocks by metamorphism without reference to the character of the original rocks. The material first determined by Wadsworth as diabase-tufa forms a part of this series. There is, however, very little true diabase in the range, while porphyrites (altered andesites) on the other hand are abundant. The bisilicate that is most common in the porphyrite is augite, but large masses contain augite in very subordinate amount. Certain very basic portions of these areas seem to have contained olivine and are probably melaphyres. The silica contents of the series ranges from 48.86 per cent. in the melaphyre-like rocks to 68.56 per cent. in the porphyrites with metasilicates in small amount, and in some areas the acid porphyries grade over into still more acid varieties containing free quartz, as in the rocks of the Gopher Ridge. (See Jackson geologic folio.) The amphibolitic schists included within the porphyrite and amphibolite areas were

[1] This porphyritic granite was wrongly designated a granite-porphyry in the Fourteenth Annual Report, U. S. Geological Survey and in the American Geologist, Vol. XIII., p. 305. A similar use of the term may however be found in Hatch's Petrology, 1892, p. 114.

[2] Auriferous Gravels, p. 44.

formed from the porphyrites, melaphyres, etc., by dynamometamorphism. So generally have all these rocks been compressed that few outcrops can be found which do not show a rough schistosity. Let us add that the structure of these porphyrites and melaphyres is so obscured by secondary minerals (uralite, epidote, chlorite, zoisite and calcite) that it is little to be wondered that their true nature has not been clearly understood. It is now plain that the chief part of the rocks laid down on the geologic map as porphyrite and amphibolite schist are altered forms of original surface lavas and tuffs corresponding to modern basalts and andesites.

As has been stated before, the oldest known rocks in the Sierra Nevada, south of the fortieth parallel, are of Carboniferous age, and in treating of the history of the volcanic phenomena of the range we will commence with that period.

In the foothills of Eldorado, Amador, and Calaveras counties (see Placerville and Jackson folios) there is a narrow belt of clay-slate in which are numerous limestone croppings, and in several of these Carboniferous fossils have been found. Interbedded with the slate and limestone at several points are layers of conglomerate, composed of well-rounded pebbles. One of these layers is exposed by the road to Plymouth, in Amador county, northwest of Sugar Loaf, and at other points, and there is another similar one (possibly the same horizon) about three miles northwest of Golden Gate Mountain in Calaveras county. It is to be presumed that these conglomerates are of the age of the enclosing rocks, and in that case the pebbles they contain indicate with certainty the kind of rocks that existed before the Carboniferous or during an earlier portion of that period. The pebbles are largely of igneous rocks, although quartzite pebbles are present. The igneous pebbles are chiefly hornblende and mica porphyrites, but holocrystalline rocks, with idiomorphic augite, plagioclase, and leucoxene enclosed in orthoclase are also represented. The leucoxene appears to have formed from ilmenite. The plagioclase is mostly decomposed, as is also part of the augite. The orthoclase is largely fresh. The last-men-

tioned pebbles may be called augite-syenite. A partial analysis of one of them (No. 30 Amador county) by Dr. Stokes of the United States Geological Survey, gave the following results:

	No. 30 Amador.	165 S. N.
SiO_2	55.45	55.04
M_gO	4.11	3.41
K_2O	5.18	1.41
N_2O	1.73	4.27

A rock in place closely resembling these pebbles has been found near Nevada City, by W. Lindgren, and is shown on his Grass Valley sheet in the Nevada City folio. To the north of Tehuantepec Valley in the area of the Downieville atlas sheet is a large mass of granitoid rock that has very nearly the same mineral composition and structure as the pebble above described. An analysis by Dr. Stokes of a specimen from this area is given above (No. 165 S. N.). This rock is composed of plagioclase, augite, rhombic pyroxene, iron ore, and brown mica enclosed in later unstriated feldspar that appears to be orthoclase, although the chemical analysis does not show enough potassa for much orthoclase to be present. The augite is plainly later than the plagioclases in places indicating a tendency to ophitic structure. There is a little quartz in the rock. All the constituents are fresh.

In the area of the Placerville sheet in southern Eldorado county, in the same belt of Carboniferous rocks noted above as containing conglomerate, there are numerous areas of igneous material. One of these, forming the hill known as Big Sugar Loaf, is a boss of porphyrite containing quartz and hornblende phenocrysts, and extending from this mass north across Slate Creek is a narrow dike containing abundant primary brown hornblende needles. This porphyrite boss is believed to represent an eruption of Carboniferous time. About three and a half miles north of Big Sugar Loaf is a hornblende-porphyrite area, and thin sections of the rock show a devitrified groundmass exhibiting flow structure. It is possible, however, to regard these masses as intrusive and younger than the enclosing slates, but

other elongated areas called diabase and porphyrite (db), on the Placerville map in the vicinity of these hornblende-porphyrite areas, are distinct tuffs and volcanic agglomerates, and there can be no reasonable doubt that the igneous fragments they contain were derived from volcanoes existing at the time the beds were forming. As hornblendic and augitic porphyrite fragments are very common in the agglomerates, we may safely assume that eruptions of porphyrite (old andesite) took place in the Carboniferous time in the foothill region. Exactly similar evidence is presented in the same belt of Carboniferous rocks in the area of the Jackson sheet. There are numerous streaks of fragmental porphyrites that are interbedded with the slates and evidently contemporaneous with them. In mapping these fragmental areas, the writer in places found much difficulty in deciding whether to lay down certain masses as pyroclastic rocks or as ordinary sediments, for there is a gradation from one to the other in places. The rule followed was to regard those layers as igneous that were chiefly composed of igneous fragments.

The most positive evidence of volcanic eruptions during the Carboniferous period has been brought forward by Diller,[1] who described a bed of tuff near Genesee Valley at the north end of the range in which Upper Carboniferous fossils were found. Mr. T. W. Stanton kindly collected a specimen of this tuff for the writer, on one side of which are shell impressions. A thin section shows numerous plagioclase phenocrysts and some non-twinned feldspars, probably orthoclase, in an altered groundmass containing very abundant minute fibers of a brightly polarizing secondary mineral, perhaps uralite. A partial analysis of this rock (No. 80 S. N.) made by Augustus Wedderburn under the direction of Professor Chas. E. Munroe, of the Columbian University, shows 5.01 per cent. of potassa, and 1.94 per cent. of soda. It is probably a trachyte.

The fossiliferous Upper Carboniferous beds on Little Grizzly Creek[2] are interbedded with porphyritic volcanic material more

[1] Bulletin Geological Society America, Vol. III., p. 374.

[2] American Geologist, Vol. XIII., p. 230, and Fourteenth Annual Report, U. S. Geological Survey, p. 448.

or less similar to that of the Robinson beds near Genesee Valley, but the rock in which the fossils occur is not itself a distinct tuff. It is composed of minute grains, probably of both quartz and feldspar, with abundant secondary greenish brown mica in minute irregular foils and green hornblende in slender fibers. The porphyritic feldspars in the tuff (No. 219, Plumas county) found just north of the Little Grizzly Creek fossil beds, and with little doubt part of the same series, appear to be largely orthoclase. Another similar tuff from an area farther south (No. 352) contains likewise large feldspars, some of them three-tenths of an inch in diameter. These are in part microcline. The same greenish brown mica found at the two other localities above described is also present in the groundmass. This and the greenish hornblende is probably the result of contact-metamorphism as granite occurs near each. A partial analysis by George Steiger, of No. 352, shows it to have approximately the composition of a trachyte.[1]

Following the Carboniferous comes the Trias. Beds of this age have been found at Mineral King, at Genesee Valley and on Rush Creek. At the latter locality is a bed of conglomerate interstratified with slate and limestone, the latter containing pentagonal crinoid stems. This conglomerate was first discovered by J. E. Mills[2] and was visited by the writer in company with Mr. Diller. The pebbles of this conglomerate are well rounded, and may have been derived from land areas composed of Palæozoic rocks. Igneous pebbles are very abundant. These consist chiefly of quartz-diorites that seem originally to have been quartz-gabbros, the pyroxene now being hornblende. One pebble is chiefly made up of hornblende derived from pyroxene with a few spots of secondary material containing aggregates of minute, black particles, representing possibly original olivine, in which case this rock was a lherzolite. This pebble may have been derived from the large area now largely serpentine that forms Red Hill, just west of Rush Creek. Mr. Mills in his bulletin states that he found pebbles of granite like that forming Spanish Peak, but he

[1] Fourteenth Annual Report, U. S. Geological Survey, p. 448.

[2] Bulletin Geological Society, Vol. III., p. 429

does not appear to have had the specimens examined microscopically. Neither Mr. Diller nor the writer found any pebbles of the Spanish Peak rock (a quartz-mica-diorite) in the conglomerate. The southern extension of the Red Hill serpentine area is shown on the geologic map a little west of Quincy.

The long belts of porphyrite and amphibolite indicated on the map on either side of the narrow belt of Palæozoic (in this case certainly Carboniferous) rocks are very probably Jura-Trias in age. In fact, certain portions are without doubt of Jurassic age. A section across the Bear Mountains, which lie east of Stockton, shows the relation of the igneous and sedimentary formations.

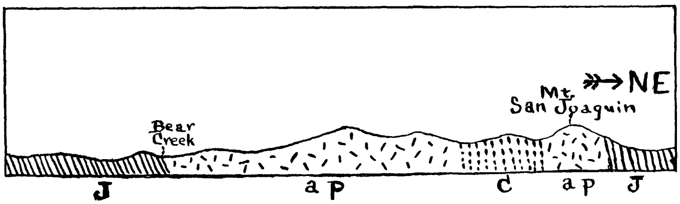


FIG. 1. Section across the Bear Mountains, extending vertically to sea-level, C.—Carboniferous slates. J.—Jurassic slates. ap.—Porphyrite, porphyrite tuffs, and amphibolite. Vertical and horizontal scale two miles to the inch.

We have here a central belt of Carboniferous slates flanked on either side by augitic porphyrites and tuffs, and at both the east and west base of the Bear Mountains are Jurassic slates, which have been designated the Mariposa formation. The porphyrites and their tuffs being surface formations, there seems good ground for regarding them as products of volcanoes that existed after the Carboniferous and before the close of the Jurassic. It may also be assumed that the portions of each porphyrite belt lying nearest the Carboniferous slates are the oldest. The tuffs along the east borders of the eastern area merge into the Jurassic slates, the latter containing frequent layers of the augite-tuff, so that it is difficult on the east slope of the Bear Mountains to draw an exact line between the tuff and the slates. There can be no doubt as to the age of these tuff layers, for in some of them ammonites have been found. The one found nearest the line of the section came from a branch of Cherokee Creek at the

east base of the Bear Mountains, and occurs in an augitic slate.[1] In the collection of Stanford University there are two specimens of ammonites from the same horizon as the Cherokee Creek specimen, although the localities are further north on the area of the Placerville sheet. The rock in which the fossils occur is a distinct augite-porphyrite tuff, and would ordinarily be called greenstone. The writer is indebted to Professor J. P. Smith for the following information concerning them: One ammonite is *Perisphinctes* conf. *colfaxi* Gabb sp., and was found by Mrs. M. J. Gates at Huse's bridge over the Cosumnes river; the other is *Perisphinctes* sp. or *Olcostephanus*, and was found in a bowlder near Nashville, Eldorado county, by J. C. Heald. Both species indicate the Upper Jura.

According to Diller,[2] the Hinchman tuff at Mt. Jura in Plumas county contains lapilli, affording evidence in that section of volcanoes during the time of deposition of the tuff (Upper Jura). Mt. Jura is perhaps one of the best places in the range for the chronological study of ancient volcanic materials, both on account of the greater freshness of the rocks and the abundance of fossils.

As will be noted on the geologic map, the large area of porphyrite and amphibolite widens going north. On the Smartsville geologic map, now being published, these rocks may be seen to occupy a large portion of the surface of the country. They have been studied mostly by Mr. W. Lindgren, who agrees with the writer in regarding them as chiefly surface eruptions and probably Jura-Trias in age. These rocks, largely augite-porphyrites and their tuffs, are presumed to have covered, as with a mantle, the underlying Palæozoic formations. There are some streaks of slates among the eruptive masses, but these have not in the Smartsville area afforded any fossils. However, during the past season, in the north extension of the same area, in a belt of clay-slate interbedded with augite-breccia and tuff, fossil plants were collected by T. W. Stanton. The exact locality is by the stage

[1] Fourteenth Annual Report U. S. Geological Survey, p. 453.

[2] Bull. Geol. Soc. Am., Vol. III., p. 373.

road south of the Oroville Table mountain, near the Banner gold quartz mine. Professor Ward examined these plant remains and expressed the opinion that they are of middle Mesozoic age, and then referred them to Professor Fontaine, whose report is herewith appended:

[*Extract from letter of Professor Wm. M. Fontaine to Professor Lester F. Ward, dated April 22, 1895.*]

I have examined carefully the plants from near Oroville, Cal., collected by Stanton and Oliver, with the following results:

1. Perhaps the most common form is a *Tæniopteris*, which I cannot distinguish from *T. stenoneura*, Schenk, found in the Grenzschichten and in the lower Rhetic of France.

2. Not uncommon is a narrow form which is most probably *Tæniopteris tenuinervis* of the same beds, and which is still more characteristic of the Rhetic.

These narrow Tæniopteris forms are the most abundant imprints among the California fossils. This type goes up, it is true, as far as the Oolite, but in species not seen among these fossils. Macrotæniopteris, if present, must be much rarer than Tæniopteris. I am not sure that any of this type is present. There is one large fragment, poorly preserved, that looks much like a Macrotæniopteris, which resembles *M. magnifolia.* There is a ribbed imprint, an imprint of the inner wall of either an Equisetum or Schizoneura. It looks more like the imprint Schenk calls *Calamites Gumbeli* of the Grensch, which Schimper makes *Equisetum Gumbeli.* There is a very fine plant of *Ctenophyllum grandifolium* of the Richmond coal field, and several fragments of the same plant. This is of great value in fixing the age of the strata, as this type of plant is unmistakable, and is not known except in the uppermost Trias and Rhetic. Schenk's *Pterophyllum carnallianum* is probably a small variety of it. I may say here that a few years ago some Mexican brought a few fossil plants from Mexico, and they were submitted to me. Among them were fine specimens of this Ctenophyllum, and from them I felt sure that uppermost Trias and Rhetic extend into Mexico.

There are several good imprints of a Podozamites which I cannot distinguish from *P. Emmonsi* of the N. C. uppermost Trias. Possibly it may be *P. lanceolatus.* If so, it is the Rhetic rather than the Jurassic type of this widely extended and persistent form of Podozamites. It is now so much expanded by species-makers that it is rather a group-type than a species, like *Pecopteris Whitbiensis.*

There are a number of scattered leaves like Schenk's *Zamites angustifolius* or more probably *Podozamites tenuistrictus* of the Richmond coal.

There is an imperfectly preserved imprint of a very large Danæopsis,

probably *Danæopsis marantacea,* another Rhetic plant. It shows the nervation and basal portion of several pinnules attached to the rachis.

There are probably three different ferns, but they are so few and in such small fragments of the terminal portions of ultimate pinnæ, that nothing of their true nature can be made out. It is impossible to say if they are Triassic or Jurassic. They have rather more of a Jurassic than a Triassic facies.

Taking all the evidence, I think it can be positively said that *this flora is not older than the uppermost Trias, and not younger than the Oolite.* I feel pretty sure that it is true Rhetic, somewhat younger than the Los Bronces flora of Newberry, and the Virginia Mesozoic coal strata. It is much like the Rhetic flora of France, made known by Saporta. At any rate, this *is a new grouping of plants that certainly deserves to be carefully collected. I do not think the fossils now in hand suffice to fix narrowly the age, which may be lower Jurassic.*

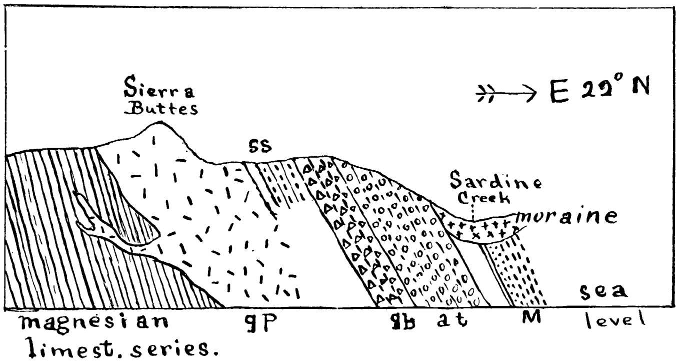


FIG. 2. Section across the Sierra Buttes. Horizontal and vertical scale one mile to the inch. qp=quartz-porphyry. qb=quartz-porphyry breccia. at=augitic tuffs. M=Milton series. ss=siliceous schist.

On the east slope of the Sierra Buttes (Downieville atlas sheet) the rocks are magnificently exposed through glacial agency, and during the past season the writer obtained evidence there of the succession (see Fig. 2) of the old volcanic rocks which form the larger part of the Buttes.

Forming the mass of the Buttes is a fine-grained rock containing abundant porphyritic quartzes. No analysis has been made of the Sierra Buttes rock, but from the north end of the same area, which extends to Eureka Peak, three specimens were collected and analyzed,[1] giving the following results:

[1] Fourteenth An. Rep. U. S. Geol. Survey, p. 473.

Silica	73.62	per cent.	to	79.41	per cent.
Lime	.09	"	"	"	2.55	"	"
Potassa	2.23	"	"	"	4.27	"	"
Soda	2.46	"	"	"	3.78	"	"

As there is some carbonate in minute particles in these rocks, it is quite likely that in the fresh rock the lime never reaches as small a quantity as .09 per cent. Although containing too much lime and too little potassa for a typical quartz-porphyry, the variation is not sufficient to exclude the rock from the quartz-porphyry group, and it will be so called here.[1]

Overlying the quartz-porphyry is a sedimentary lens, partly a dark siliceous schist and partly coarser material, dipping easterly at angles of from 50° to 60°. In this lens is the quartz vein of the Mountain mine. At one point in the sedimentary mass is a layer of quartz-porphyry about 50 feet thick which may be an intruded sheet or a contemporaneous flow. Radiolarian-like remains were noted in the sections of a dark, fine-grained breccia that forms part of this clastic series. This sedimentary mass has been designated a "lens" since it feathers out both to the north and south. Other lenses, usually entirely made up of dark siliceous schist and slate, occur in the Sierra Buttes, from one of which at the Phœnix mine an ammonite was collected.[2] Some of these lenses are entirely enclosed in the quartz-porphyry, and it is probable that the entire series, the quartz-porphyry as well as the overlying formations, is Jura-Trias in age.

Superimposed with apparent conformity on the clastic series just described is a breccia containing abundant angular microlitic fragments and angular quartzes which are in part idiomorphic. This series is designated in the section a quartz-porphyry breccia, overlying which is a huge bed of altered augitic pyroclastic rock without free quartz. Moraine material covers the lower part of the slope, but one mile further south in the bed of the North Fork of the North Fork of the Yuba River, this augitic tuff is

[1] Cross gives analyses of two quartz-porphyries from Leadville that contain very similar silica, lime and alkali ratios to those given above. Monograph XII., U. S. Geol. Survey, p. 326.

[2] Am. Geol., Vol. XIII., p. 232.

plainly seen to be conformably overlain by the red slates and fine-grained tuffs of the Milton series. Near Milton, there is good evidence that this last series is unconformable on the Palæozoic rocks to the west. These Palæozoic rocks are called in the section the magnesian-limestone series, there being in it frequent irregular masses of magnesian limestone, but no fossils have been found in any portion of it, and it is presumed to be Palæozoic in age on account of the highly metamorphosed condition of most of the material composing it. There are dikes of quartz-porphyry in the magnesian-limestone series. The dip of the pyroclastic and clastic rocks overlying the quartz-porphyry of the Sierra Buttes is to the east at angles varying from 50° to 60°. The dip of the Palæozoic rocks to the west is often vertical, but dips to the east at high angles have been noted at many points. While these dips represent in part the dip of the original stratification, at some points they probably indicate the dip of the schistosity.

To the east of the Milton series is a large granite mass which appears to be of later age, since the Milton rocks show evidence of contact metamorphism.

There are then at the Sierra Buttes an acid volcanic series (quartz-porphyry and quartz-porphyry-breccia), with an overlying augitic pyroclastic series more basic in composition, and later than the whole volcanic series, a deep-seated intrusive acid rock (granodiorite).

The succession of the effusive rocks, acid quartz-porphyries, and more basic augitic tuffs, is strikingly similar to the succession of the Tertiary effusives, rhyolites and andesites, described hereafter.

In addition to the above rocks, there are in the same region numerous dikes cutting the various igneous formations. Thus the quartz-porphyry of Eureka Peak (same area as that of the Sierra Buttes) is cut by dikes of an altered rock that appears to be an aplite (No. 150 Plumas), and also by a more basic rock, probably originally an augitic porphyrite (Nos. 385 and 386 Plumas), but the idiomorphic phenocrysts of this are now

fibrous hornblende. On the southwest slope of Mt. Elwell, the augitic tuffs that overlie the quartz-porphyry series are cut by a dike of a white rock (No. 108 Plumas) of a fine-grained granular structure, and composed of quartz and feldspar with smaller amounts of secondary epidote and fibrous hornblende. The rock is thought to be an aplite. The same augitic tuff series at a point about one and three-fourth miles southeast of Mt. Elwell is cut by a dike of hornblende-porphyrite (No. 206 Sierra county). Forming the east base of Eureka Peak is a dark, coarse, granular rock which is seen under the microscope to be a gabbro. The contact of this rock with the quartz-porphyry is sharp, and as there are angular fragments of the gabbro enclosed in the porphyry, it appears that the gabbro is the older rock. At a point eight-tenths of a mile (No. 133 Plumas), and at another point one and three-fourths miles southeast of Eureka Peak, there are in this gabbro white dikes that microscopically appear to be aplites. Cutting No. 135 is a darker colored dike (No. 136) which contains outlines of squarish crystals, one showing truncated corners, presumably originally augite (but now replaced by calcite, epidote, quartz and chlorite), in a microlitic feldspar groundmass. In a ravine on the northeast slope of Eureka Peak enclosed in the quartz-porphyry there are fragments of a rock weathering reddish (No. 383 Plumas). On microscopic examination these proved to be apparently quartz-diabase, identical in structure with the rock (No. 550 Calaveras) that occurs as a dike in the granitoid quartz-porphyry southeast of Milton near Rock Creek (Jackson atlas sheet). The rock is ophitic in structure, the divergent plagioclases penetrating the quartz grains as well as the chlorite and epidote which seem to represent original augite. In No. 550, the metasilicate is chiefly hornblende, which is presumed also to have been augite. In addition there are numerous grains of iron ore. This peculiar ophitic rock has thus far been noted by the writer only at the two points above mentioned. As the rock needs more investigation, it will not be further considered here.

Six and seven-tenths miles southeast of the Sierra Buttes in

the granite (granodiorite) is a dike of augite-porphyrite (No. 226 S. N.) in which the augite is largely altered to fibrous green hornblende which is grouped in radiating brushes. Some of the augites are unaltered at the center with a rim of the coarsely fibrous hornblende. If there was olivine in the rock, it is now completely gone. The rock is dark green in color, strongly resembling the rock that forms a small area on the summit of the highest of the Sierra Buttes, and this latter rock appears to have contained olivine and would then be a melaphyre. Along the augite-porphyrite dike (No. 226 S. N.) is a white dike (No. 227 S. N.) about two feet wide which thus occurs between the augite-porphyrite and the granite. This rock appears to be a micropegmatitic form of aplite. The time relation of the augite-porphyrite and the aplite was not ascertained.

Chemical analyses of the dikes have not been made, but if the writer is correct in his determination of these altered rocks, we have the following succession in the Eureka Peak–Sierra Buttes region.

MEDIUM BASIC -	Gabbro — Boss.	
ACID - - - -	Quartz-porphyry — effusive, large sheet.	
MEDIUM BASIC -	Augite porphyrite — effusive, mostly tuff, large sheet.	
ACID - - - -	Granite (granodiorite).	Intrusive.
ACID - - - -	Aplite.	Intrusive.
BASIC - - - -	Augite-porphyrite (?) or melaphyre (?)	Intrusive.
MEDIUM BASIC (?)	Hornblende-porphyrite.	Intrusive.

The relative age of the aplite, late augite-porphyrite, and hornblende-porphyrite yet remains in doubt, the only evidence being that the greenish dike (No. 136), apparently an augite-porphyrite, cuts the aplitic dike (No. 133).

In the area of the Jackson sheet are a number of bodies of rock that are designated on the geologic map of that area as quartz-porphyrite. Analyses[1] of these rocks, however, show them to have a composition very similar to the quartz-porphyry of the Sierra Buttes. The quartz-porphyrites should perhaps be restricted to altered andesitic rocks with free quartz, and with less than 70 per cent. of silica, corresponding to modern dacites.

[1] Fourteenth An. Rep. U. S. Geol. Survey, p. 484.

If this rule be followed, all of the quartz-porphyrites of the Jackson geologic map should be called quartz-porphyries. The following analyses, however, show that the lime and alkali ratios are very similar in the Jackson sheet quartz porphyries, and in typical dacites, so that in reality they constitute a group intermediate between typical quartz-porphyries and typical quartz-porphyrites.

	Dacites				Quartz-Porphyries		
	129	131	A	B	151	553	549
SiO	65.66	67.49	69.51	68.20	70.29	71.19	72.24
CaO	3.64	2.68	1.71	4.33	2.30	2.87	3.40
K_2O	2.03	2.40	3.34	1.52	3.05	1.82	.39
N_2O	3.65	4.37	3.89	2.98	2.68	4.24	4.43

Dacites 129 and 131 are from Sepulchre Mountain,[1] and the two designated as A and B are from Lassen Peak, Cal.[2]

Nos. 151, 553 and 549 are from the area of the Jackson sheet.

These rocks with porphyritic quartzes seem usually to be intrusive in more basic igneous rocks, augitic porphyrites and amphibolite-schist. An exception to this rule is the rock of the south part of the Gopher Ridge, south of the Salt Spring Valley reservoir. This grades over into a porphyrite containing augite, and is probably older than quartz-porphyries 553 and 549 which occur at the west base of the range, and are almost certainly intrusive, and, as no analysis has been made of it, it should perhaps be properly called a quartz-porphyrite and not a quartz-porphyry, on the basis above stated.

Intrusive in the augite-porphyrite and tuff that forms the western ridge of the Bear Mountains is a dike of serpentine, originally a peridotite or pyroxenite.

We have then in the Jackson sheet area:

Intermediate	Augitic porphyrites — Effusive.
Basic	Peridotite — Intrusive.
Acid	Quartz-porphyry — Intrusive.

[1] Thirteenth An. Rep. U. S. Geol. Survey, p. 648.

[2] Bull. No. 9, U. S. Geol. Survey, p. 16.

The time relation of the peridotite and quartz-porphyry is not known to the writer.

At the south end of the Gold Belt in Mariposa county there is a very interesting series of igneous rocks, the oldest of which appear to be augite-porphyrites and their tuffs, and their dynamometamorphic derivatives, some of which may be Palæozoic, and others Jura-Trias in age. They in no way differ from similar rocks that have been described above from the Jackson sheet area and elsewhere. These surface augitic volcanics are interbedded with schists and slates, and the entire series is cut off and metamorphosed by the granite a little south of the town of Mariposa (see Plate VII.) About Cathey Valley and westward from there to Hornitos are considerable areas of a dark granular rock some of which is seen under the microscope to be typical diabase with ophitic structure. In portions of the area the augite is replaced by brown hornblende, and the rock is then an ophitic diorite. No. 446, Sierra Nevada collection, probably represents nearly the average composition of this diabase. This specimen is from a dike by the road northeast of Hornitos. It is composed of augite and hornblende apparently intergrown, in which are imbedded feldspar laths. The area about Cathey Valley forms much the largest area of true diabase known to the writer in the Sierra Nevada. As the rock occurs in dikes in the greenstone tuffs and schists (augitic tuffs and their derivatives), it is evidently younger than at least a portion of the greenstone series.

Forming the high ridge east of Cathey Valley, and abutting against the coarser hornblendic granite that cuts off the slate series south of Mariposa, is a fine-grained granite in places practically an aplite. This fine-grained granite may be but a modification of the coarser granite, but is thought to be later. Ferro-magnesian constituents are rare in the larger part of the area, much of which may be called a soda-aplite (see analysis No. 413). Analysis No. 369 is of the coarser granite, from the Chowchilla River, and from the west edge of the same granite mass that cuts off the Mariposa slates west of the town of Mariposa, metamor-

ANALYSES OF PRE-TERTIARY IGNEOUS ROCKS.

SPECIMEN NUMBER.	PORPHYRITE.	AUGITIC TUFF.	MELAPHYRE?	PERIDOTITE.	DIABASE.	QUARTZ-MICA-DIORITES (GRANODIORITES).			HBL.-MICA POYPHYRITE.	PORPHYRITIC GRANODIORITE.	APLITES.		DIORITE (?)
	25 S. N.	19 S. N.	26 S. N.	325 S. N.	446 S. N.	71 S. N.	303 S. N.	369 S. N.	304 S. N.	39 S. N.	413 S. N.	161 S. N.	250 Butte.
SiO_2	68.58	54.66	49.24	44.81	51.32	67.33	68.65	62.62	66.65	66.28	74.21	76.03	57.87
TiO_2	.57	.67	.96	1.88	1.23	.36	.28	.55	.33	.54	.30	.07	.53
Al_2O_3	13.04	15.85	14.79		15.28	15.93	16.34	17.51	17.61	16.03	14.47	13.39	16.30
Cr_2O_3	..	..	..	.29	..	..	..	..	..	..	..	..	..
Fe_2O_3	.26	1.82	1.52	1.98	.47	1.90	.93	.49	.93	1.80	.35	.48	1.71
FeO	3.40	5.12	8.00	4.52	8.59	1.59	1.48	4.06	1.67	1.88	.50	.31	3.86
MnO	.15	.18	.18	.13	..	.09	.08	.05	.07	.05	none	trace	.08
NiO	..	..	..	.09	.16	..	..	..	..	..	..	..	..
CaO	3.22	8.75	10.74	6.58	11.58	4.09	3.07	5.49		3.75	1.71	1.28	5.53
SrO	strong trace	trace	trace	none	faint trace	trace	.07	trace	4.44	trace	trace	trace	trace
BaO	.10	.04	.04	none	none	.08	.09	trace	.12	.08	none	.04	.05
MgO	1.01	5.64	6.89	30.91	7.25	1.63	1.29	2.84	1.26	1.12	.28	.05	5.50
K_2O	1.90	.47	.88	.15	.22	2.46	1.85	1.76	1.70	3.49	.10	5.18	.75
Na_2O	4.94	3.46	2.76		2.92	3.76	4.85	3.49	4.59	4.10	7.62	2.98	5.01
Li_2O	none	none	trace	..	faint trace	trace	trace	trace	trace	trace	trace	none	trace
H_2O below 110° C.	.16	.25	.20	.15	.06	.19	.24	.22	.03	.11	.15	.15	.26
H_2O above 110° C.	1.00	2.48	2.97	6.88	.95	.66	.62	.92	.41	.39	.23	.34	2.40
P_2O_5	.20	.15	.17	.02	.25	.11	.15	.12	.18	.30	.07	.03	.27
CO_2	1.31	.39	.90	1.79	..	..	..	..	..	..	..	..	..
FeS_2	.15	.09	..	..	..	..	..	..	..	..	..	..	..
	99.99	100.02	100.08	100.18	100.28	100.18	99.99	100.12	99.99	99.92	99.99	100.33	100.12

phosing them near the contact into mica and andalusite schists. In Yaqui Gulch some of the latter contain impressions of shells of *Aucella erringtoni*, Gabb, proving their upper Jurassic age. No. 399 is the fine-grained granite from Agua Fria Creek and not far from its contact with the coarse granite. Its mineral composition is not greatly different from that of the coarse granite as represented by No. 369. It is microscopically a micropegmatite with minute foils of brown mica gathered in groups. No. 413 is a white medium-grained rock, and a fair sample of the larger part of the area. It is composed of feldspar and some quartz plainly discernible as such, with a large amount of micropegmatite. In Cathey Valley and to the southeast of it, the diabase before described and the fine-grained soda-granite come in contact, forming a zone of contact-breccia in places more than a mile wide. The fragments of diabase are cemented together by white feldspathic material presumably from the granitic magma, indicating the later age of the white granite.

The augitic porphyrites of Mt. Bullion, north of Mariposa, are cut by a dike of serpentine, doubtless originally a peridotite.

Near Mormon Bar, south of Mariposa, is a dike of hornblende-porphyrite in the coarse granite.

The succession of the old igneous rocks in the Mariposa region is then, so far as made out, as follows:

Augite-porphyrite, chiefly tuff, effusive.	
Diabase,	Intrusive.
Serpentine,	
Coarse granite (quartz-mica-diorite),	
Fine-grained granite (aplite),	
Hornblende-porphyrite.	

As bearing on the age of the hornblende-porphyrite, it might be stated that at many points the granite and other rocks are cut by dikes of a dark rock containing original hornblende, some occurrences of which are granular in structure and allied to diorite, and others have a distinct groundmass and are more correctly called hornblende-porphyrite. An analysis of one of these (No. 250 Butte county collection) is given in the table. This is apparently holocrystalline, but the feldspar between the

idiomorphic hornblendes has crystallized in ill-defined branching forms. In the feldspathic material there are numerous minute green dots that appear to be chlorite. The analysis corresponds closely to that of the augitic tuff (19 S. N.) and to the composition of some pyroxene-andesite except that soda is greatly in excess of potash.

There are abundant dikes of fine-grained white granites (aplites) in the coarse granite of the Sierra Nevada. These in general have very nearly the composition of typical granites. They contain, as a rule, very little mica or hornblende. An analysis of one of these dikes is given in the table (No. 161 Sierra Nevada collection). The specimen was taken two miles southeasterly from Deadman's Peak, in the area of the Downieville sheet. It will be observed that the rhyolites, Nos. 126 Amador and 365 Plumas, have practically the same chemical composition as the aplite.

The volcanoes of Jura-Trias time in the Sierra Nevada appear to have been much more active than those of Palæozoic time, judging from the evidence offered in the preceding pages, and from that exhibited by the maps of the Gold Belt now being issued.

Following the Jura-Trias there seems to have been a long period during which the volcanic action was quiescent. This period apparently comprised most of Cretaceous and Eocene time.

The main facts concerning the age and succession of the Tertiary lavas of the Sierra Nevada have already appeared in print,[1] and only a short statement will be here inserted, together with some additional information obtained lately.

The first Tertiary eruptions, the relative age of which is clear, occurred apparently in Miocene time. These consisted of flows of rhyolite, which filled many of the old river valleys, but do not appear to have covered the higher ridges. The Miocene age of

[1] Am. Jour Science, Vol. XLIV., pp. 455–459; Am. Geol., Vol. XI., pp. 309–316; and the Fourteenth An. Rep. of the Director U. S. Geol. Survey, pp. 493–495.

the rhyolite-flows is shown by the plant remains occurring chiefly in clay beds of the Neocene Auriferous gravels with which the rhyolitic material is associated. Some of these clays have been thought themselves to be decomposed rhyolitic material. These plant remains, chiefly leaves, have been studied by Lesquereux, Ward, and Knowlton. Professor Lesquereux, it is true,[1] first considered the plants from the Auriferous gravels to indicate a Pliocene age for the containing beds, but in a more recent report[2] he refers other plants from the same, or possibly a somewhat later horizon, to the Miocene.[3]

Analyses of two rhyolites are given in the table (Nos. 126 Amador county, and 365 Plumas county). A number of partial analyses have been made of rhyolites from other localities, and all show a remarkably uniform silica, lime, soda, and potash ratio.

In Butte and Plumas counties there are extensive tables of a dense fine-grained black basalt, represented in the table of analyses by No. 276 Plumas county, and No. 18 Sierra Nevada. At many points the tables of this basalt are capped with andesite-breccia, showing that it is earlier than the andesite. Its age relative to the rhyolite is not known to the writer, but it is thought to be later, since the gravels which it covers at some points appear to belong to later channels than those covered by the rhyolite. Still, at Sawpit, northwest of Onion Valley (Downieville atlas sheet), this older basalt covers the older white quartz gravels, and on the Oroville Table Mountain it caps the Ione formation.

After the rhyolite and older basalt flows there was a period of erosion before the main andesite eruptions. These were of hornblende-pyroxene-andesite, an analysis of an average sample of which is given in the table (No. 72 Sierra Nevada collection). Much of the andesite occurs in the form of a tuff or breccia, and

[1] Memoirs Museum of Comp. Zoöl., Vol. VI., No. 2, p. 54.

[2] J. S. DILLER, Eighth An. Rep. U. S. Geol. Survey, p. 419.

[3] The age of the Auriferous gravels is discussed in a paper by DILLER (JOURNAL GEOLOGY, Vol. II., pp. 32–54) and in a paper by the writer to appear in the American Geologist, June 1895.

ANALYSES OF TERTIARY IGNEOUS ROCKS.

SPECIMEN NUMBER.	Rhyolite.		Older Basalt.		Table Mt. Basalt.	Hbl.-pyr. Andesite.	Hbl.-Andesite.	Late Pyroxene-Andesites.				Qtz-Andesite.	Late Doleritic Basalt.	
	126 Amador	365 Plumas.	276 Plumas.	18 S. N.	36 S. N.	72 S. N.	16 S. N.	262 S. N.	1829 Cascade Range.	209 S. N.	661 S. N.	626 S. N.	311 Plumas.	314 Plumas.
SiO_2	73.23	71.39	50.56	50.66	56.19	58.47	60.20	59.34	68.12	66.94	56.90	60.02	53.91	52.81
TiO_2	.09	.17	1.71	2.39	.69	.51	.57	.32	.25	.30	..	.42	.52	.84
Al_2O_3	12.73	14.13	14.71	13.97	16.76	18.80	17.21	17.61	16.24	16.49	..	16.07	17.95	16.60
Cr_2O_3	..	..	..	..	..	..	..	..	none	..	..	trace	..	..
Fe_2O_3	.99	.63	3.54	2.55	3.05	3.34	3.12	3.63	1.26	1.41	..	2.17	2.21	2.66
FeO	.16	.37	8.90	10.20	4.18	2.64	2.69	2.28	2.08	1.87	..	3.46	4.80	6.13
MnO	trace	trace	.13	.29	.10	.13	.12	.12	.10	.13	..	.10	.10	undet.
NiO	..	..	..	trace	..	..	..	..	..	..	..	none	..	..
CaO	.61	1.01	7.58	8.08	6.53	6.60	6.04	6.45	3.80	4.77	7.83	7.01	10.40	10.14
SrO	none	trace	trace?	trace	strong trace	.05	trace	.04	.02	.05	..	trace	trace	trace
BaO	.02	.09	.25	.22	.19	.09	.11	.11	.09	.07	..	.08	.05	.03
MgO	.22	.08	4.07	4.45	3.79	2.69	3.18	3.50	1.35	1.98	..	4.57	5.52	6.12
K_2O	5.17	5.69	2.10	1.95	4.46	2.01	1.44	1.94	2.54	1.65	1.37	1.59	1.34	1.05
Na_2O	1.91	2.89	2.94	3.32	2.53	3.58	3.35	3.40	3.89	3.88	3.24	3.55	2.90	2.79
Li_2O	trace	trace	trace?	none	trace	trace	trace	trace	trace	trace	..	none	trace	trace
H_2O below 110° C.	.53	.42	1.06	.27	.34	.14	1.12	.64	..	.35	..	.24	.20	.38
H_2O above 110° C.	4.51	3.32	1.12	.43	.66	.92	1.18	.74	.40	.22	..	.45	.20	.54
P_2O_5	.02	.03	1.14	1.01	.55	.22	.17	.25	.14	.12	..	.17	.21	.23
SO_3	..	..	..	Cl..02	..	..	..	..	..	..	..	SO_3.06	..	..
	100.19	100.22	99.81	99.81	100.02	100.19	100.50	100.37	100.28	100.23	..	99.96	100.31	100.32

appears to have issued from fissures near the summit of the range, mixed with water, forming enormous mud flows which covered a large part of the western slope of the range. At Poker Flat (Downieville atlas sheet) Canyon Creek cuts across a huge fissure filled in part with rubble of the adjacent rocks, but chiefly with fragmental andesite. This was at first taken to be evidence that the mud flows became such before issuing from the inner regions, that is to say, the volcanic material was thought to have been broken and mixed with water within the earth. The creek has cut to a depth of 1000 feet or more through this fragmental dike, without reaching the bottom of it. During the past season, however, another similar occurrence was found, where it is plain that the fissure was filled from above. This second instance is about one and one-fourth miles south of Cammel Peak (Bidwell Bar atlas sheet), in the canyon of Fall River. The stream has cut into this second fragmental dike of andesite-breccia to the depth of about 500 feet, and in the dike material in the bed of the river are imbedded numerous fragments of fossil wood. These pieces of wood must have been washed into this fissure from the surface together with the andesitic material in which they are imbedded. The specimens of wood collected were referred to Professor F. H. Knowlton, who reports that "it is a *Sequoia* of the redwood, or *S. sempervirens* type. The wood is not well enough preserved to enable me to say that it is the same as the living redwood, although it is undoubtedly near it."

Fragmental volcanic rocks are usually supposed to have been formed by explosive action, the material being thrown out as fragments and ashes, which, falling on the surrounding land, or in bodies of water, would in the former case assume a roughly and in the latter a definitely stratified shape. But this does not seem to form an adequate picture of the Pliocene andesitic eruptions of the Sierra. As before stated, the fragmental andesite appears to have been mixed with water, perhaps derived from melting snow at or very near the sources of the eruption. But however these mud flows were formed, on their course down the slopes of the range they caught up much foreign material. Silici-

fied trunks of both deciduous and coniferous trees, bowlders of granite, some of them tons in weight, and pebbles and fragments of nearly all the older rocks of which the Sierra Nevada is composed, are found imbedded in the andesitic material.

Along the east side of the Great Valley of California these andesite-tuffs grade into well-stratified material containing abundant rolled sand grains, and such areas may be regarded as water deposits. A most remarkable fact has been noted by the writer in regard to these tuff areas, and that is that wherever the original top layer of the beds has been preserved this is, so far as observed, a distinct breccia, composed chiefly of angular fragments and blocks cemented by ashes, while below are layers of

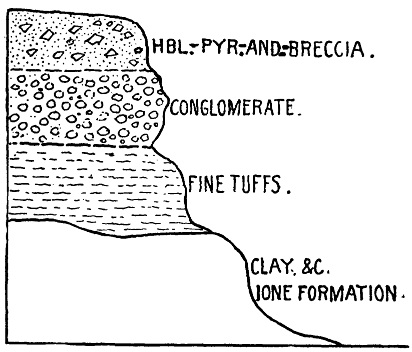


FIG. 3. Lava-capped hill four miles west of Ione. Elevation about 400 ft. above base.

fine tuff and volcanic conglomerates The accompanying section (Fig. 3) represents the layers composing a flat-topped hill about four miles west of Ione, in Amador county.

With variations as to the layers of conglomerate and tuffs in their number and thickness, this section may be verified at a great number of points in the foothill region. The andesite of the breccia eruptions is a coarse-grained rock. It is shown in the table of analyses by No. 72 Sierra Nevada, which came from the southwest base of Mt. Ingalls. No. 16 Sierra Nevada is a massive occurrence of a similar coarse andesite, but differs from No. 72 in containing hornblende to the exclusion of pyroxene.

In the area of the Downieville and Bidwell Bar atlas sheets

are numerous bodies of a dense fine-grained gray lava, which usually weathers with a slaty fracture, the apparent cleavage being often vertical. The rock is composed of plagioclase, augite, a slightly pleochroic rhombic pyroxene, and grains of magnetite The feldspar, augite, and rhombic pyroxene are in the form of minute elongated prisms or laths, and this is true of the rock at widely separated localities, and the laths of all are nearly of the same size. About half a gram of No. 661 powdered and treated with HCl by George Steiger yielded no gelatinous silica, but nevertheless there appears to be some glass present.

Three analyses are given in the table of this pyroxene-andesite. The analysis of No. 1829 Cascade Range collection[1] is of a specimen collected by Mr. Diller, from the west summit of Crater Peak (Lassen Peak atlas sheet); No. 209 Sierra Nevada is from the high point one and one-fourth miles northeast of Goodyear's Bar; and No. 661 is from Franklin Hill (Bidwell Bar atlas sheet). The analyses of 1829, and 209 are by Dr. Hillebrand, and the partial analysis of 661 is by Dr. Stokes. In the vicinity of Poker Flat are numerous dikes of another fine-grained andesite very similar in general appearance to the variety just described. It differs in being frequently columnar, and microscopically in containing a little hornblende and in the feldspars being less uniform in size and shape. At one point on the summit of the ridge south of Poker Flat a dike (No. 631 S. N.) of this rock cuts the hornblende-pyroxene-andesite-breccia. Another and larger dike cuts the pre-Tertiary rocks east of Poker Flat. It crosses Canyon Creek just east of the mouth of Illinois ravine, and to the southeast of Poker Flat forms a conical butte showing columnar structure. An analysis of the latter dike is given in the table (No. 262 S. N.). This andesite is therefore later than the hornblende-pyroxene-andesite-breccia. The exact relative age of the similar fine-grained andesite (Nos. 1829, 209 and 661) is still in doubt, but it is thought to be of about the same age as the andesite (Nos. 631 and 262) just described.

The rock called quartz-andesite (No. 626 S. N.) in the table

[1] Bull. No. 60, U. S. Geol. Survey, p. 157, No. 19.

of analyses of Tertiary rocks is not a dacite. The quartzes are much corroded and surrounded with reaction rims of pyroxene microlites. They may perhaps be regarded as inclusions. The rock has a pilotaxitic structure, and seems related to the fine-grained pyroxene-andesites. It forms a flat-topped hill on the ridge two miles northwest of Downieville.

Following the andesite eruptions we have at many points flows of basalts. Some of these, as, for example, the coarse doleritic basalts of Mt. Ingalls in Plumas county, are believed to belong to early Pleistocene time, for the eruptions seem to have occurred after the present drainage system was partly formed. However, on the north side of the mountain glacial striæ are to be seen on the lava, showing the flow to have taken place before the close of the Sierra Nevada glacial epoch. The doleritic basalt is represented in the table of analyses by Nos 311 and 314 Plumas.

There are at many points isolated buttes and dikes of fine-grained basalts that do not resemble closely either the older basalt above described or the Pleistocene doleritic basalt. There is usually abundant olivine in these rocks, but their groundmass is much finer grained than that of the doleritic basalt. Their age is presumed to be Pleistocene. A dike of one of these rocks cuts the coarse andesite, and the underlying gravel of the point sometimes called Mt. Etna, one mile northeast of Mt. Fillmore (Downieville sheet) by the road to Johnsville, and similar dikes cut the Neocene fragmental material exposed on the southeast slope of Mt. Fillmore.

To the north of the Sierra Nevada at Cinder Cone,[1] near Lassen Peak, and about Mono Lake[2] just to the east, as well as in the Coast Range to the west near Clear Lake,[3] craters exist that retain nearly or quite their original forms. These volcanoes are without doubt of late Pleistocene age. Within the Sierra Nevada, however, if the range be limited as suggested in the beginning of

[1] Bull. No. 79, U. S. Geol. Survey, by J. S. Diller.

[2] Eighth An. Rep. Director U. S. Geol. Survey, pp. 378–389.

[3] Monograph XIII., U. S. Geol. Survey, p. 246.

this article, no eruptions are known to have occurred since early Pleistocene time.

The succession of the Tertiary volcanic rocks is then as follows:

ACID - - - - - - - -	Rhyolite — massive and fragmental.
BASIC - - - - - - - -	Older basalt — always (?) massive.
INTERMEDIATE - - - -	Hornblende-pyroxene-andesite — chiefly tuff and breccia.
INTERMEDIATE TO ACID -	Fine-grained pyroxene-andesites — massive.
BASIC - - - - - -	Doleritic basalts — massive.
BASIC - - - - - - - -	Other basalts — massive.

This succession does not accord with the law of Richthofen nor with Iddings' law, but it should be noted that the record here given is an imperfect one.

According to Dr. James Blake,[1] there is a variety of volcanic rocks in the Puebla Mountains in Northern Nevada forming successive flows, the relative age of which is very clear, as the series is finely exposed. Dr. Blake made some chemical determinations of the igneous rocks, but they do not appear to have been studied microscopically. Indeed, at that time (1873) the microscope was in little use in rock investigation. His conclusion as to the succession is that it does not accord with Richthofen's law, but the series he describes obviously needs further investigation.

Iddings' law[2] is perhaps the latest that has been formulated with great care and after a consideration of the succession in many parts of the world, with a large amount of original research based on extensive field study and collections at various volcanic centers in the West. It is as follows:

> The variation in the composition of igneous rocks, which constitute a series of eruptions at any volcanic center, is the result of the chemical differentiation of some intermediate magma. The composition of the intermediate magma may be different in different centers of eruption and in different regions, and it will be shown subsequently that the intermediate magma of any particular center may itself be the result of a differentiation of a more ancient magma or of a primary uniform magma, if such a thing can be shown to have existed.

[1] Proc. Cal. Acad. Sci., Vol. V., pp. 210–214.

[2] Bull. Phil. Soc., Washington, Vol. XII., p. 151.

Brögger in a late paper on the basic igneous rocks of Gran, in Norway, writes as follows:[1]

We have consequently in the basic rocks of Gran a remarkable example of the fact that one and the same magma *partly* without essential differentiation has been pressed up to a higher level, and there has crystallized out as large boss-masses (in the form of olivine-gabbro-diabase), *partly* has been differentiated at a deeper-seated level into a basic magma (which by its outburst has formed sheets and dikes with porphyritic structure, camptonites) and into a more acid residuary magma (which in the final eruptions has given rise to sheets and dikes of bostonite). This differentiation (into camptonites and bostonites) has partly also taken place in the dike and sheet-fissures themselves *after* passing up into a higher level.

This certainly confirms Iddings' law in a remarkable degree.

The chemical analyses of the igneous rocks of the Sierra Nevada given in the two tables, pages 403 and 407, are arranged as nearly as the writer is able in their order of succession. Considering now the Sierra Nevada as a whole as a petrographic province, there are certain relations which seem to suggest that Iddings' law may be applied here.

The oldest of the pre-Tertiary rocks which have a wide distribution are the augitic tuffs and breccias. These are chiefly of an intermediate character. The serpentines (originally peridotites and pyroxenites) are at a number of points clearly intrusive in, and therefore later than, these augitic tuffs. It seems to be also true that the quartz-mica-diorite (granodiorite) is later than the serpentine. This relation has already been noted[2] to the southeast of Placerville, and the quartz-mica-diorite of Indian Valley (Downieville sheet) sends out a dike-like protrusion into the serpentine where exposed in the bed rock of the Indian Hill gravel mine. In the bed of Mill Creek, one and one-half miles northeast of Big Bar Hill (Bidwell Bar atlas sheet), a dike of biotite-granite cuts the tremolite and chlorite schists which are altered forms of pyroxenites, and are in this section associated with serpentine as part of the same rock mass. About two and one-half miles south of Big Bar Hill

[1] Quart. Jour. Geol. Soc., Vol. L., p. 29.

[2] See Am. Geol., Vol. XI., p. 310.

there are streaks of serpentine, amphibolite and quartz schists forming one series which is cut off by a protrusion of the large Merrimac granite area. The succession of the most abundant of the pre-Tertiary rocks of the Sierra Nevada would then be:

INTERMEDIATE -	Augitic porphyrites and their tuffs — effusive.
BASIC - - - -	Peridotites and Pyroxenites — intrusive.
ACID - - - -	Quartz-mica-diorites — intrusive.

Brögger has introduced a term that promises to be of much use to petrographic science. He writes:[1]

For rock-types, differentiated out of a common magma, I propose the name "complementary rocks;" camptonites and bostonites are then such complementary rocks.

The serpentine, a very basic rock, and the quartz-mica-diorite are thus perhaps later differentiations from the intermediate magma of the augitic porphyrite eruptions. It is obviously unsafe, however, to generalize on the meager data presented as to the age of all of the augitic tuffs, serpentines, and granites of the Sierra Nevada. Instead of there being one series of these pre-Tertiary rocks, it is much more probable that there are two, a Palæozoic and a Jura-Trias series, and it is far from improbable that the succession is more complicated than represented here.

Later than the quartz-mica-diorite and serpentine are the aplite dikes or veins and the late hornblende-porphyrite dikes, and these may possibly be "complementary rocks" also. Both are nearly of an age, but they are not found together, so far as the writer has observed. The dikes of hornblendic rock are abundant in the Spanish Peak and the Merrimac (Bidwell Bar sheet) and the West Point (Jackson sheet) granitic areas; and the aplite dikes are common in most of the granitic areas, but as before stated are not associated with the hornblendic dikes.

H. W. TURNER.

[1] Quart. Jour. Geol. Soc., Vol. L., 1894, p. 31.